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PROFILING OF A DISC CUTTER FOR CUTTING LARGE WHEELS

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Abstract: *This article shows a principled approach through application of the method of wrapping the treated surface in its variety - a method of coating design - to profiling the work of the disc cutter for cutting gears with larger modules (m≥10mm). Their requirements for accuracy and roughness of the gears' side surfaces are not very high, due to the nature of work, as they are used to drive different types of drums in the cement, mining, food and other industries.*
This profiling approach allows to be manufactured a prefabricated disk cutter, which has some very important advantages, such as lower manufacturing cost, simple forms of the body and teeth (usually plane and rotational), better productivity, which is a result of sharply ground teeth.
In the paper is also shown a construction of a disk prefabricated cutter, designed by the authors, which is used for milling of teeth of a gear with module 20 mm (m = 20 mm).

Key words: *cylindrical gear, disc cutter, large modules, profiling, structural wrapping method.*

1. BASICS OF THE METHOD OF STRUCTURAL WRAPPING

Profiling the teeth of prefabricated disk cutter is appropriate to use the method of structural wrapping (non-centroid wrap) [3 and 4].

Profiling the teeth's working part of the tool is so consistently cutting teeth to wrap the tooth profile of the cutting wheel. Each tooth of the router has a different profile angle defined so that its side cutting edges (blades) to touch the face involution surface.

When using this method of profiling the cutter's blades are accepted as rectilinear [5]. Straight side cutting edges of the cutter can be maintained as such unless the rear surface is formed flat, i.e. disc cutter teeth are formed as sharp.

To determine the profile angle in any point of contact of the side cutting edge of disk cutter to a tooth of the wheel is introduced a coordinate system with origin *O* of the sprocket wheel axis and *Y* axis y_0, which halves its tooth gap (Fig. 1).

Major influence on the size of the profile angle of the cutting teeth has the disk cutter teeth number z_0.

Contact of the cutting edges of the teeth in question happens to involute profile at fixed points depend on:

- radius of the point of the wheel involute profile;
- profile angle of the tooth cutting edge.

When adopted number of teeth $\mathbf{z_0}$, value of the *i-th* radius is:

$$r_N = r_A - \sum_{i-1}^{z_{0-1}} \Delta r, \qquad (1)$$

where $\Delta r = \dfrac{r_A - r_L}{z_0 - 1}\cdot$

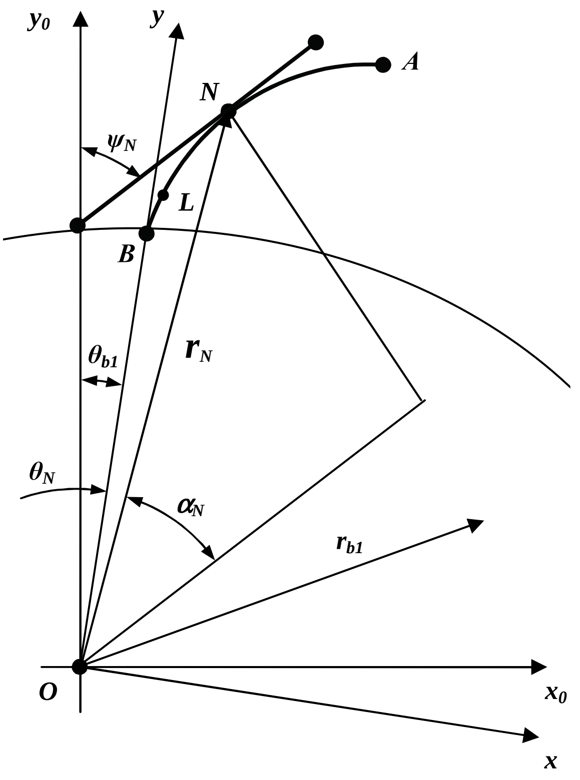

Fig. 1. Calculation scheme for profile angle determination.

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Profile angle ψ_N of tooth, which contacts in the point *N*, is formed between the tangent to this point of involute profile and the vertical axis Oy_0 of the wheel's teeth gap. It is determined by the relationship:

$$\psi_N = \alpha_N + \theta_N + \theta_{b1}. \quad (2)$$

Parameters in equation (2) are determined by formulas given in [1]:

$$\alpha_N = \arccos\left(\frac{r_{b1}}{r_N}\right); \quad (3)$$

$$\theta_N = \tan\alpha_N - \alpha_N; \quad (4)$$

$$\theta_{b1} = \frac{p_{b1} - S_{b1}}{2r_{b1}}; \quad (5)$$

where p_{b1} and S_{b1} are step and tooth thickness of the core circle of the wheel.

2. DETERMINATION OF PROFILE ERROR OF WHEEL TEETH

To determine the error that will be received by the enveloping surface formed by rectilinear cutting teeth of the cutter and theoretical involutes profile of gear, it is necessary to determine their mutual disposition relative to one another.

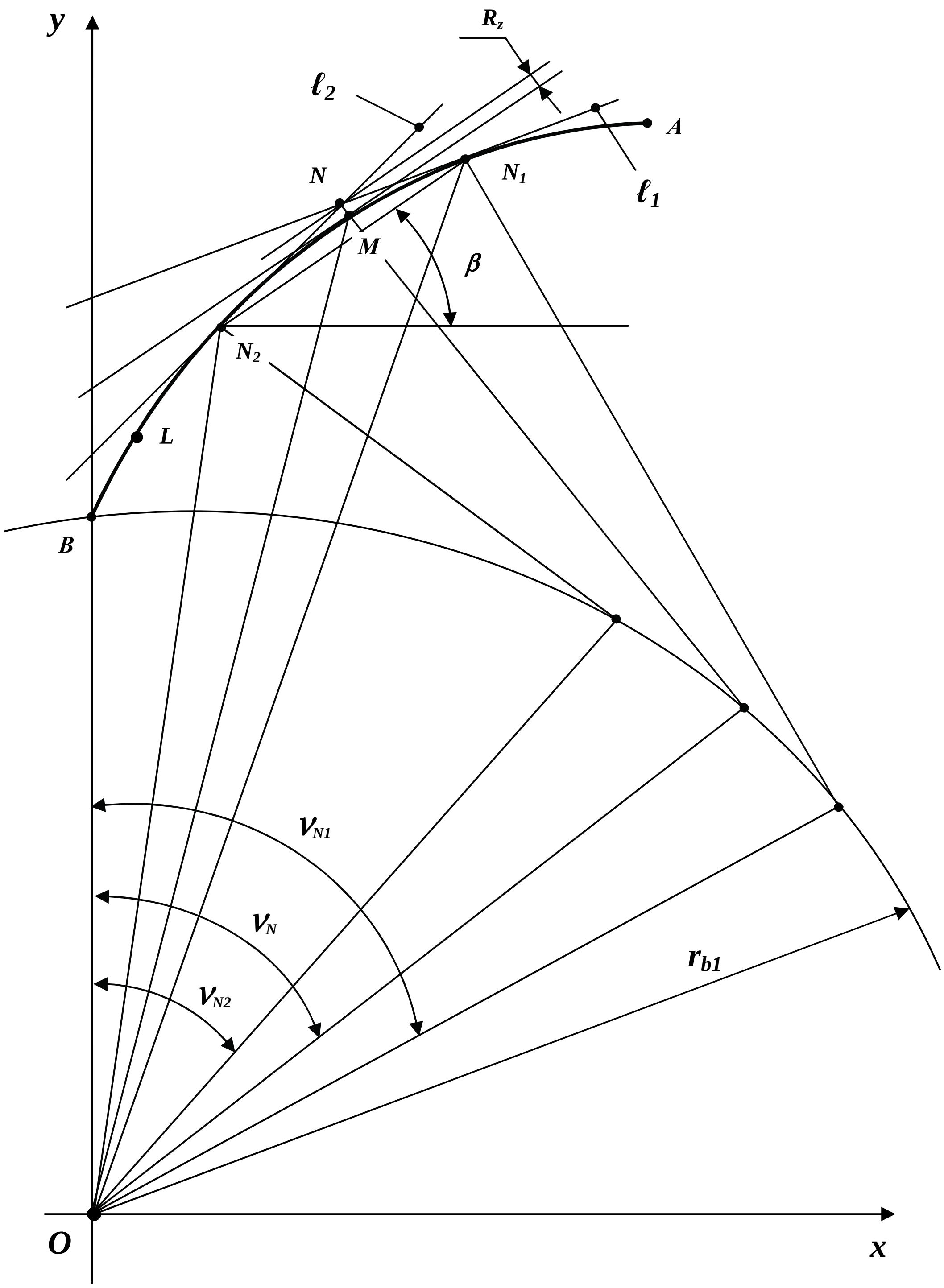

Fig. 2. Scheme for error determination of the involute profile of the gear.

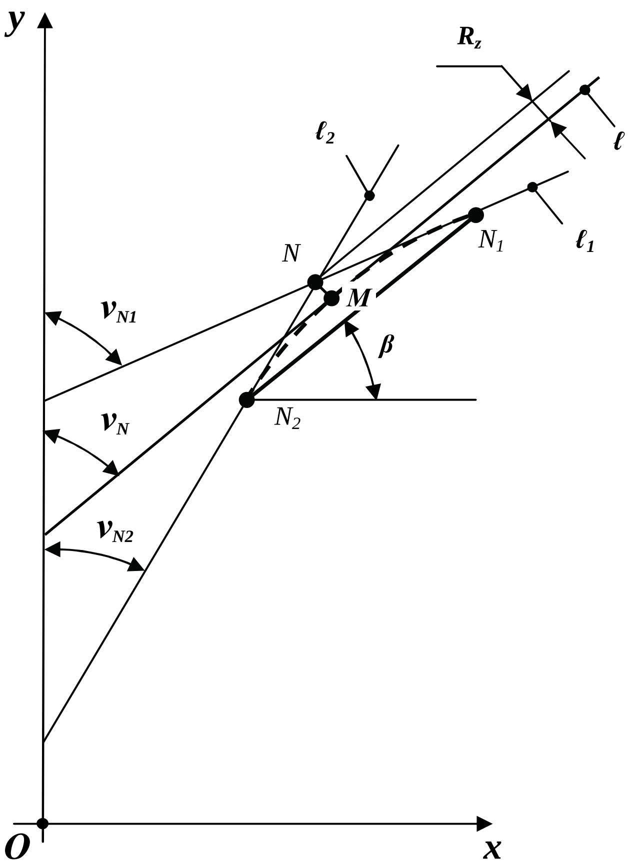

Fig. 3. Determination of the involute profile error.

The lateral involute surface of the worked gear tooth, which is obtained by the method of coating (noncentroid wrap), is a result of the successive positions of rectilinear cutting edges of cutter ℓ_1 and ℓ_2 (Figs. 2 and 3).

The maximum error of the side evolving profile of the gear cut is obtained from the intersection point of two adjacent cutting teeth of the tool ℓ_1 and ℓ_2 in point N and involute line of the tooth – M, examined in xOy coordinate system (Fig. 3) marked with R_z.

The equations of two adjacent side cutting edges of the disk cutter, depicted by lines ℓ_1 and ℓ_2 are [2]:

- for the line ℓ_1

$$y_1 - y_{N1} = a_1(x_1 - x_{N1}), \tag{6}$$

where $a_1 = \tan\left(\frac{\pi}{2} - \nu_{N1}\right)$.

- for the line ℓ_2

$$y_2 - y_{N2} = a_2(x_2 - x_{N2}), \tag{7}$$

where $a_2 = \tan\left(\frac{\pi}{2} - \nu_{N2}\right)$.

Angles ν_{N1} and ν_{N2} (Fig. 3) are the involute development for the corresponding points and are determined using the dependence:

$$\nu_i = \alpha_i + \theta_i. \tag{8}$$

The coordinates of point N_1 (x_1, y_1) and point N_2 (x_2, y_2) at given development angles ν_{N1} and ν_{N2} are defined as:

- for point N_1

$$x_{N1} = r_{N1}.\sin\theta_{N1},$$
$$y_{N1} = r_{N1}.\cos\theta_{N1},$$

- for point N_2

$$x_{N2} = r_{N2}.\sin\theta_{N2},$$
$$y_{N2} = r_{N2}.\cos\theta_{N2},$$

- for the line ℓ_1

$$y_1 = a_1.x_1 + b_1, \tag{9}$$

where $b_1 = y_{N1} - a_1.x_{N1}$.

- for the line ℓ_2

$$y_2 = a_2.x_2 + b_2, \tag{10}$$

where $b_2 = y_{N2} - a_2.x_{N2}$.

The intersection point of two lines (N) is:

$$x_N = \frac{b_1 - b_2}{a_2 - a_1},$$
$$y_N = \frac{b_1.a_2 - b_2.a_1}{a_2 - a_1}. \tag{11}$$

The shortest distance from point N to the involution line is the segment $\overline{NM}$ (Fig. 3).

Line ℓ, which osculates the involute in point M, joins angle ν_M with the ordinate y axis. According to the theory of involute gearing, this angle is the angle of involute development:

$$\nu_M = \frac{\pi}{2} - \beta, \tag{12}$$

where $\beta = \arctan\left(\frac{y_{N1} - y_{N2}}{x_{N1} - x_{N2}}\right)$.

The parameters of section M – radius r_M, profile angle α_M and involute angle θ_M, when they are from the involute line, should be determined in an iterative manner [3], so as to comply the equation (12).

The coordinates of point M in the coordinate system xOy are defined as [1]:

$$x_M = r_M.\sin\theta_M,$$
$$y_M = r_M.\cos\theta_M. \tag{13}$$

The equation of line, which passes through point M, is:

$$y - y_M = a_M(x - x_M). \tag{14}$$

To obtain the equation (14) in the Cartesian form after its processing:

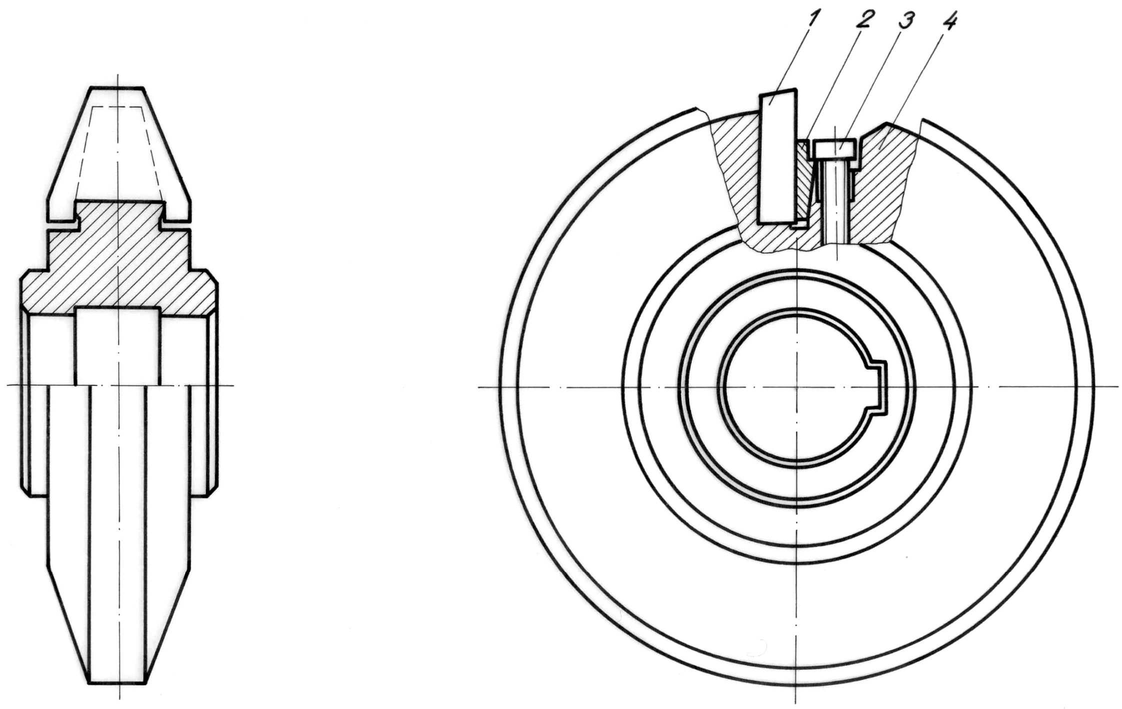

Fig. 4. Structure of a prefabricated disk cutter: 1 – cutting tooth; 2 – pressing cotter; 3 – screw; 4 – body.

$$y = a_M . x + b_M , \quad (15)$$

where $a_M = \tan\beta$ is the angular coefficient of the line

$$b_M = y_M - a_M . x_M .$$

The distance $\overline{NM}$ is the maximum deviation (error) of R_z, which is obtained for the profile of the gear, when in profiling of cutting teeth is applied the method with noncentroid wrap and is defined as:

$$R_z = \frac{y_N - a_M . x_N - b_M}{\sqrt{a_M^2 + 1}} . \quad (16)$$

In formula (16) by substituting the value of the angular coefficient of the line, which passes through point *M*, the discrepancy is obtained:

$$R_z = \frac{y_N - \tan\beta . x_N - b_M}{\sqrt{(\tan\beta)^2 + 1}} . \quad (17)$$

Estimated maximum deviation should be less than allowable one, determinate according to the degree of accuracy of the gear:

$$R_z \leq [R_z] = f_{f_r} , \quad (18)$$

where f_{f_r} is the error of involute profile of the gear tooth.

3. APPLICATION

The construction of the prefabricated disc cutter, designed by the authors, is shown on Fig. 4. The specialty of this construction is, that the joining surfaces of the body 4 (Fig. 4) and the cutting tooth 1 are plane. This gives advantages in the constructive forming, as follows:

- the plate joining surfaces are easy for technological manufacturing;
- universal machine tools are used;
- precise measuring tools are used for their control.

The realization of elementary plane surfaces of the tooth of cutting part and joining surfaces is made through using sharpening device, shown on Fig. 5. Grinding of all surfaces is made on a universal flat-grinding machine and it is an essentially technological advantage for realization of the tool.

The back surfaces are three – left and right side back surfaces and back surface to the top. The last one is the same for all teeth of the tool and that's why they are sharpening simultaneously. The side back surfaces, which have different profile angle, are sharpening as the basic plate 1 of the device (Fig. 5) is used as "sinus ruler". This gives the possibility the profile angle to be obtained with high precision.

Using tool for rough working, for which the main characteristics is that teeth have the same form and size, the device is manufactured in such a way which allow all back surfaces of the disc cutter teeth to be sharpen with. This guaranteed uniformity of the size received and their possibility to be replaceable during usage, too.

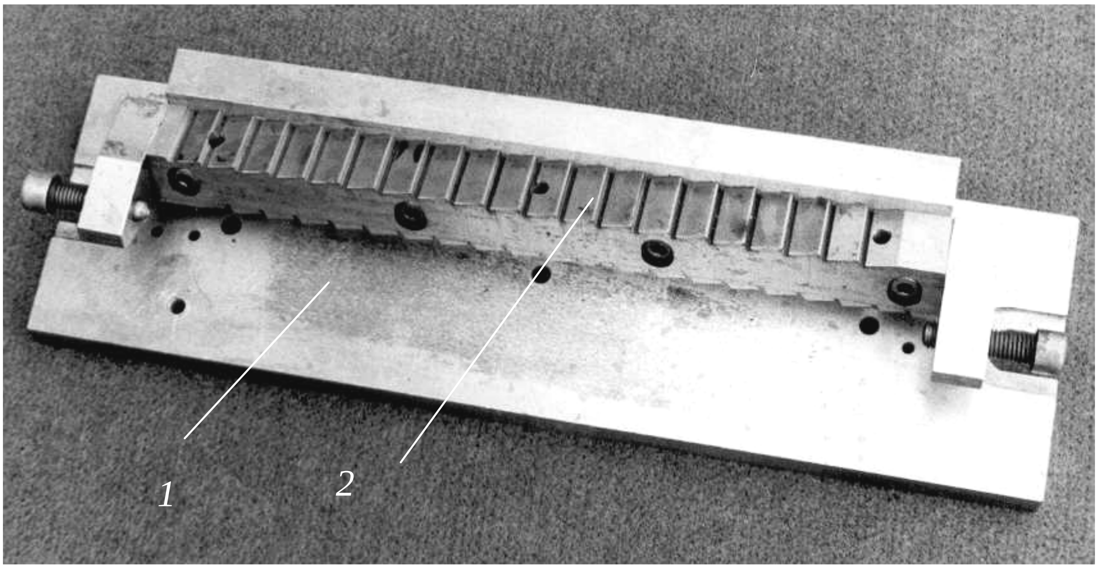

Fig. 5. Device for sharpening of the teeth of prefabricated disc cutter:
1 – basic plate; 2 – rack.

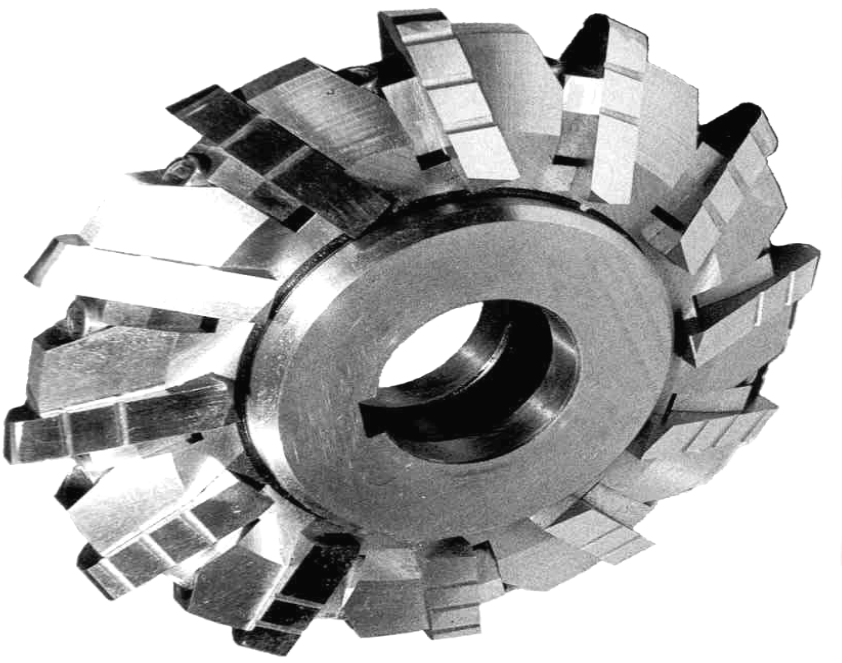

Fig. 6. Specimen of the disc cutter prefabricated module m = 20 mm.

The outer diameter should be selected as high as possible and its maximum value depends on the concrete teeth-milling machine. Using higher diameter for a given module, the diameters of the arbors' holes, respectively arbors of the machine tool, have to be increased. This is the way to increase the stability of the tool during its work.

Having higher outer diameters, the number of teeth could be increased, too. This influenced auspicious on the preciseness of the profile of the gear teeth, because the number of tool's teeth forming the real profile of the gear teeth is increased.

Having general increase of the cutter teeth number will bring to increase number of simultaneously working teeth. In this way the dynamic loading of the system through the teeth-milling process is improved.

We should not miss the negative influence of increasing outer diameter, either – it increases the needful time for cut into the tool.

So, when select the outer diameter we have to aim at its increase, but having in mind the time for cut into the tool, or seeking after a rational variant in outer diameter choice.

Using a trial model of prefabricated disc cutter for rough cut (Fig. 6), are made tests in the factory of heavy engineering – Ruse. It was processed a gear, having characteristics as follows:

- module – m = 20 mm,
- number of teeth – z_1 = 58,
- wide of teeth ring – b = 400 mm,
- material – steel 45L.

The gear has been cut in milling machine ZFWZ 2000/20, using working conditions, as follows: velocity V = 20 m/min, minute feed S_M = 36 mm/min and cutting depth t = 40 mm.

The results, which have been received, give good reason to accept that the proposed prefabricated disc cutter, which is special in its essence, in technological, constructive and exploitation way responds to the demands for prefabricated tools.

Measurements were conducted on the location of assemblies to the body of the cutter, which showed that they haven't changed their original position.

The results, obtained in measuring the gear, show that the proposed construction of a prefabricated disk cutter could be used for rough machining of gears.

4. CONCLUSION

The theoretical-applied formulas, which have been developed, allow to design methodic of profiling disk prefabricated cutter.

Using the methodic, could be prepared a document for producing disk cutters.

4.1. The theoretical development for profiling the cutting edges of disc cutter for cutting cylindrical gears with involute profile are formalized such a level, that it is possible to develop a software system by which to alleviate iterative process of calculation and improve the results.

4.2. The developed modular disc cutter could be used for clean and rough machining of gears with modules $m \geq 15$ mm.

4.3. By rationally constructed basic elements of prefabricated disc cutter - cutting teeth and body, enables them to be realized using universal machine tools.

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